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An integrated system framework of building information modelling and geographical information system for utility tunnel maintenance management

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ABSTRACT

Utility tunnel should be well maintained for it services public pipelines and city operation. In the recent time, utility tunnel has been operated via computer maintenance management systems (CMMS) or building automation systems (BAS). However, CMMS or BAS lack of convenient visualization and interoperability. This paper aims to propose an integrated system of building information modelling (BIM) and geographic information system (GIS) to improve the performance of current maintenance management system. A system framework of BIM-3DGIS is proposed and required maintenance management functions are also developed based on practice demands. A real case of utility tunnel is used to demonstrate the system. Two scenarios and a questionnaire survey are conducted to validate the applicability and practicability. Results show that the proposed BIM-3DGIS system can ensure effective maintenance works and have well potential applications.

1. Introduction

Rapid growths of urban city and underground construction have resulted problems in arranging underground space for assorted utilities such as essential pipes and cables (Canto-Perello et al., 2013). The expanding population with demands of diversified services makes the maze of underground pipes and cables even more complex. Utility tunnel, an underground tunnel which includes electric power, water, communications, heating lines, gas and other public services, is introduced as a useful and sustainable solution (Canto-Perello and Curiel-Esparza, 2013). The utility tunnel enables installation, maintenance and removal of public service pipes and avoids street cuts or excavations. Meanwhile, it also avoids former messing underground pipeline layout.

The utility tunnel makes public service pipes more efficient and cost-saving management, but it also increases the complexity and difficulties among different public service pipes in a limited underground space. Moreover, utility tunnel is the lifeline of urban city since it contains essential public services which support residential life and industry. Therefore, the utility tunnel needs to be efficiently and effectively maintained as every equipment problem or failure needs to be solved immediately and precisely to avoid serious operational and economic consequences. Previous researches had studied the risks and compatibility among different pipes (Canto-Perello and Curiel-Esparza, 2003; Curiel-Esparza and Canto-Perello, 2005; Fouladgar et al., 2011; Ghorbani et al., 2012) and the maintenance management issues (Ben-Haim, 2012; Canto-Perello et al., 2009; Curiel-Esparza et al., 2004). However, a visual and comprehensive maintenance management system with information technology still needs to be developed to protect utility tunnel from potential threats.

Computerized maintenance management systems (CMMS) support operators to make maintenance planning, execution, assessment, and improvement (Kullolli, 2008) and are proved to bring a lot of benefits to today's AECO (Architecture-Engineering-Construction-Operation) industry such as increased productivity, reduced costs, and effective utilization of assets (Durán, 2011). However, CMMS are not user friendly due to it fails to provide an easy-to-understand interface (Al-Jumaili et al., 2014), visualize related assets and interoperate with other facility management systems such as acquisition of monitor data (Al-Jumaili et al., 2014; Tretten and Karim, 2014). As utility tunnels are located under the ground and the entrances are narrow. Facilities in it are enormous and three-dimensional distributed. Two-dimensional visualization cannot meet the maintenance management needs. Thus, the demand of 3D visualization of utility tunnels is important. 3D visualization helps maintainers to realize utility tunnel environment and objects, and then facilitates better decision-making. Monitoring data enable managers to better understand current operating status of the utility tunnel, detect and treat equipment failure immediately. So, maintenance management system should also include monitoring data

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to support efficient maintenance and avoid problem accumulation.

Utility tunnels are long distance infrastructure, which sometimes across the city and usually have multiple entrances for staff to access. Operators have to consider the above-ground construction and surrounding environment when arranging maintenance work to choose the most suitable entrances and exits. Therefore, maintenance management of utility tunnels also needs to be considered in a wider range of geographic information.

Building Information Modelling (BIM) is a unified information exchange platform for AECO industry which contains detailed information about facilities and equipment, and Geographic Information System (GIS) is a computer system for entering, storing, querying, analyzing and displaying geographic data. Although researchers utilized BIM, GIS (or 3D GIS) to establish tunnel maintenance system (Li and Jiang, 2010; Liu et al., 2009; Sandrone and Labiouse, 2017; Suo and Wang, 2013; Vossebeld and Hartmann, 2014; Zhou et al., 2017), a BIM and 3D GIS integrated framework for utility tunnels maintenance management is seldom proposed. Previous research (Yamamura et al., 2017) figures out the integration of BIM and 3D GIS has advantages in visualization, data abundance, large area facilities interpretation, which would be the trend of computerized management and visualization of infrastructures (Breunig and Zlatanova, 2011; Döllner and Hagedorn, 2008; Liu et al., 2017). The above-mentioned demands for visualization and data interoperability may also be solved by BIM and 3D GIS framework. Therefore, this paper proposes a system based on BIM and 3D GIS to help operators to conduct a comprehensive and overall maintenance management of utility tunnels. BIM and 3D GIS provide a source of information to maintenance management system and ultimately used as a visualization platform. This paper contributes to the existing body of knowledge by implementing BIM and 3D GIS in utility tunnel maintenance management with a focus on visualization, monitor data integration and maintenance management system development.

The rest of this paper is organized as follows. Section 2 presents the introduction of the relevant infrastructure maintenance management methods. Section 3 presents a system framework of BIM and 3D GIS to support utility tunnel maintenance management. In Section 4, the application of this framework will be demonstrated via a real project. Finally, Section 5 concludes this study as well as some discussions.

2. Literature review

2.1. Applications of BIM on infrastructure maintenance

A well-maintained infrastructure is crucial to perpetual economic growth and social development of modern society (Frangopol and Liu, 2007). Several researches have introduced methodologies to support maintenance and management of multiple types of infrastructures, including bridges (Hu et al., 2015; Li et al., 2016; Sawo and Kempkens, 2017; Zhang et al., 2016), roads and railways (Khouzani et al., 2017; Pan et al., 2016; Sadeghi et al., 2017; Setianingsih et al., 2017), tunnels and underground spaces (Jia et al., 2014; Li and Jiang, 2010; Wang et al., 2017). Several basic researches aim to develop essential management framework for infrastructure maintenance management were also proposed, such as a condition, safety, optimization and life-cycle cost based civil infrastructure maintenance and management framework (Frangopol and Liu, 2007). However, infrastructure maintenance and management still faces challenges such as performance monitoring, data management, etc. (Atkan et al., 2000; Parlikad and Jafari, 2016).

BIM—an open standard and platform of facility information creating, storing and exchanging—has gained extraordinary consciousness and adopt in the AECO industry. BIM can leverage the overall management of infrastructures. By coordinating and visualizing various kinds of data (including non-graphical data), it can manage the asset network more effectively and optimal capital, time and resources for intended purpose (Bradley et al., 2016). Infrastructure contractors and engineers have accelerated the application and deployment of BIM to replace the previous 2D management pattern and large number of static documentation (Chang and Lin, 2016; Ding et al., 2017; Hoeber and Alsem, 2016; Tezel and Aziz, 2017). However, there are four research gaps still exist: (1) information integration, (2) data integration engine, (3) BIM process and business process alignment, (4) information governance framework (Bradley et al., 2016).

Compared to other infrastructure projects, underground space projects are facing more complex geological conditions, unpredictable factors (such as water gushing and fragile surrounding rock), and higher requirements of operation and maintenance (Zhou et al., 2017). The current adoption of BIM in lifecycle operation and management of urban tunnels proved to be more efficient. (Min and Yi, 2016; Zhou et al., 2017).

To apply BIM in tunnels and underground spaces, several researches proposed data standards and modeling methodology (Koch et al., 2017; Lee et al., 2016). Xiong et al. (2016) developed an collaborative framework for tunnel construction and can be extended to operation and maintenance management phase. Hossam et al. (2016) attempted to establish a tunnel BIM model for tunnel structure maintenance and management.

Utility tunnel can be regarded as a special kind of tunnels or underground spaces, which contains massive public services pipelines and equipment. Researches on utility tunnels are mostly focused on planning (Canto-Perello et al., 2016, 2009), design (Canto-Perello and Curiel-Esparza, 2001; Chen et al., 2012; Luzhen et al., 2010) and construction phase (Mohamed and AbouRizk, 2005; Petrukhin et al., 2013). Few researches focus on operation and management, while mostly are about risk management (Canto-Perello et al., 2013; Curiel-Esparza and Canto-Perello, 2005; Mao and Zhang, 2017). There is still a lack of researches to support an effective utility tunnel maintenance management, especially with the application of BIM to provide an integrated system framework. As mentioned in Section 1, utility tunnels have characteristics such as long mileage and concealing under the ground, which BIM cannot completely solve the problem of navigation and surrounding environment visualization.

2.2. Integration of building information modelling and geographic information system (GIS)

While it represents facility's physical model, functional characters and rich construction information, BIM does not include much surrounding information which is needed to environmental evaluation, resource arrangement and safety analysis (Rafiee et al., 2014; Yau et al., 2014). For example, geological information, which is essential to the design, construction and operation of tunnels and underground spaces, can be accessed in GIS. At present, more and more researchers are trying to combine BIM and GIS.

GIS focuses on the shape of buildings and building components from a geographic perspective, while BIM focuses more on detailed building components and project information from an architecture and construction perspective (Cheng et al., 2015). Although BIM and GIS have dissimilarities such as different developmental stages, different spatial scales, different semantic and geometric representations (Liu et al., 2017), combination and integration of these two different concepts still attract many researchers, as it is an opportunity to make different information complement and develop a more comprehensive information platform to support facilities life-cycle operation and management.

2D GIS cannot explicitly support new applications such as facility management and risk management which require information about facility interiors and 3D geometry attributes (Breunig and Zlatanova, 2011). Researches focused on adding 3D models to 2D GIS and extending 2D GIS to 3D GIS have increased significantly (Breunig and Zlatanova, 2011).

To overcome data and format gap between BIM and GIS, new data standards or translation methods of existing standards are introduced